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this paper. The coast-line is taken from the Admiralty chart, while the interior I have filled up from our observations and rough plans made on the spot. It may afford some idea of the country, and serve until some one, with greater advantages, makes a better.

Brunei, November, 1858.

XVI.—*Surface Currents of the Bay of Bengal during the South-West Monsoon.* By J. A. HEATHCOTE, Esq., I.N.

Read, April 28, 1862.

THE subject of ocean currents is one in which the Royal Geographical Society has always taken a deep interest, both on account of its intimate connection with the science to which this Society particularly devotes itself, and also from its immediate practical utility. Much benefit has already accrued to navigation and commerce from the study of the circulation of the surface currents of the ocean; yet much remains to be done in the same direction, and with a promise of equally beneficial results.

The section of this subject to which I have particularly applied myself is the Bay of Bengal. Surrounded as that Bay is by the centres of trade of the various provinces on its shores—Akyab, Rangoon, Moulmein, and Penang on the east; the naval station of Trincomalee, Madras and several smaller ports in the same Presidency, and Calcutta on the west; all these places having constant intercommunication between themselves, and also with the countries of Europe, with China, and with America—the importance of this sea as a great highway of commercial traffic particularly recommends it to attention, while my own connection with it on surveying duties gave me a special interest in it, and moreover it gave opportunities of ascertaining facts, collecting information, and observing effects which have been of material assistance in prosecuting the subject of this paper.

The Bay of Bengal has not hitherto had that particular attention paid to it which must be necessary before any true determination of existing ocean currents can be arrived at. Horsburgh has given a short general account of these currents, but he omits details,—indeed he had not the opportunity of ascertaining them. He gave valuable information and the best that could be obtained at the time he wrote, but some of his statements are merely deductions by analogy, and it is not to be wondered at that experience has proved him to be sometimes, though not often, in error. Horsburgh having been the only available authority, he has been made use of wherever physical geographers of this or other countries, in elucidating the general set of the main currents

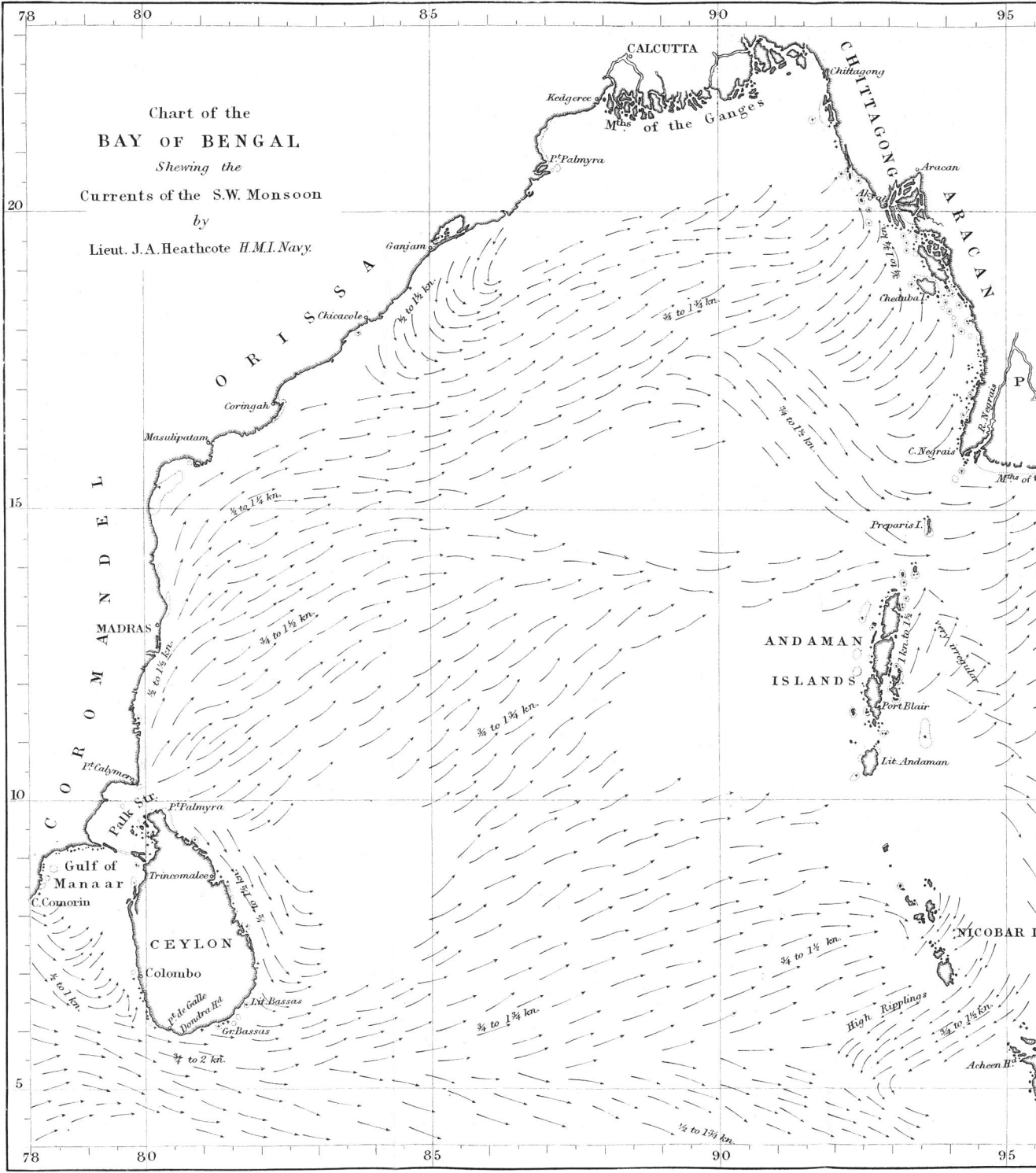


Chart of the
BAY OF BENGAL
Shewing the
Currents of the S.W. Monsoon
by
Lieut. J.A. Heathcote H.M.I. Navy.

of the ocean, have been obliged to include some representation of the Bay of Bengal; but I believe I am right in stating that this sea itself has not received their particular attention, and this may perhaps be accounted for by the fact that it was believed that it did not play any important part in the system of the great oceanic currents, and at the same time it did not present the attraction of an inland sea in which currents did undoubtedly exist, such as the Mediterranean and the Red Sea, where the opportunity might arise of propounding an interesting theory of the circulation of its waters.

A set of current charts for the Indian and China Seas for every month of the year, by Lieut. Fergusson, I.N., has been published; but they are on a small scale, and contain a mere sketch of the subject, and they are moreover, as far as the Bay of Bengal is concerned, frequently in error.

It may be well, before I describe the currents themselves, which I have ascertained from an accumulation of well authenticated facts, to show in what manner the chart of these currents has been constructed, and whence the materials were drawn, that the Society may be able to judge of the degree of credibility that may be attached to the result. The materials have been gathered from the Log-Books of the old East India Company's trading vessels, and those of H.M. ships which have been employed in the Indian Seas. The Log-Books of the old Indiamen, that is the Indiamen of thirty years ago, have been chosen in preference to those of other merchant vessels of the present day, because, by the kind permission of the Secretary of State for India, I was able to obtain them in any number at the Indian Office, and because I believe that, for the most part, more attention was at that time paid to those particular details of navigation upon which a knowledge of existing currents depends, than is generally to be found at the present day, when facilities for making use of celestial observations have so much increased as to render what is technically called "dead reckoning" the less absolutely necessary, and consequently the less particularly attended to. In the Indiaman I found a vessel with every means for good and reliable astronomical observations, but at the same time under the necessity and in the practice of paying a close attention to the computation of the ship's position from a carefully estimated course and distance run. This therefore presented the best material for my object. But, in order to make use of data of the present time as well as those of an earlier period, I have taken care to extract from the Log-Books of H.M. ships which have been employed in the Bay of Bengal of late years the result of their experience in the currents of that sea.

Permission and facilities for doing this were courteously afforded me by the Secretary of the Admiralty and Admiral Washington,

and by these means I have been able to avail myself of the experience of a great number of navigators of the first ability during the last forty years. Steam vessels have been avoided—for their passages are not well adapted to show the influence of the currents they may encounter. In a long run of 200 and 250 miles a day, they may have passed through or been influenced by more than one current of different direction and force; and yet the result of their reckoning will show only the combined effect of these different currents, and can be no guide to the separate influence of each.

The difference between the position of a ship as computed by dead reckoning, and that ascertained by astronomical observations, is generally put down to the influence of currents; and this makes up the chief material of which current charts are mostly composed; but it can only be accepted after very strict scrutiny and with many reservations. Numerous elements of error have to be avoided as far as possible. Inattention to the variation or the local deviation of the compass in use will considerably affect a ship's reckoning, and its results may be erroneously set down to the influence of currents,—bad steering or neglect of a proper computation of leeway may likewise have their effects attributed to currents,—but a careful examination of the Log Book will lead to the detection of many of these errors, and will point out in a great measure what may be received as a reliable indication of a current, and what should be rejected as untrustworthy. This will always be a great safeguard, and to it may be added, after such selection, that of the acceptance of the experience of the many, in preference to the exceptional evidence of one or two isolated instances, however well founded. For this purpose the testimony of as many cases as possible has been brought to bear on all the principal points. The number of logs made use of in this computation is one hundred and five.

My investigations have been limited at present to the currents of the south-west monsoon. It is at this season that the greatest dangers are presented to navigation, and that the currents are the strongest for weal or woe, and it is of these only that I propose to treat.

Ceylon.—From the south-west corner of the peninsula of India, the current of the south-west monsoon runs in a direction varying from south-east to south-south-east, according to the distance from the land, and at the rate of $\frac{1}{2}$ to $1\frac{1}{2}$ mile per hour until, about the latitude of Point de Galle, it is diverted into a more easterly course. On the line between Cape Comorin and Point de Galle there is a strong set into the Gulf of Manaar, which begins from 30 to 35 miles outside this line, and may prove a source of danger. Vessels from Bombay to the eastward should therefore be careful

to keep within the limits of the favourable south-easterly current. South of Ceylon, within 30 miles of the coast, the current runs strongly to the eastward from $\frac{3}{4}$ to 2 miles an hour; but farther south, that is, between the parallels of 4° and 5° , its direction is more southerly, or about E.S.E.

On the east coast of Ceylon a strong current exists to S.S.E. and S., taking more or less the direction of the land, and running at the rate of $\frac{1}{2}$ to $1\frac{1}{2}$ mile an hour, or as much as 40 miles a day.

The inaccuracy of a deduction of Horsburgh is here apparent. He states the current at this season to be here running in an entirely opposite direction, that is to the northward; for he argues that as it runs to the southward in the north-east monsoon, it may most probably run in a contrary direction in the opposite monsoon. Such, however, is not the case. This southerly current is well established: not only are numerous instances of its effects on record, as those of the *London* in July, 1830, the *Warren Hastings* in June, 1833, the *Kellie Castle* in May and June, 1833, and H.M.S. *Cambrian* in July, 1850, amongst many others, but the result of my own investigations has also been confirmed by the observations of officers very recently employed on the survey of the east coast of Ceylon. This current is felt not farther than from 40 to 50 miles off shore, and from its eastern limits a north-easterly set begins. I think it very possible that future observations may prove that this current is a return of that which flows with great velocity round the south-east corner of Ceylon to the north-eastward, a portion of which may be found to bend to the northward; for under circumstances somewhat analogous a return current of this description is found off Cape Guardafui in Africa. At the Basses Rocks it is met by that already described as setting eastward off the south coast of the island; and they both together then take a north-easterly and afterwards an east-north-easterly direction across the bay; except that, in the vicinity of the parallel of 5° north, the set is less northerly, while south of that parallel it becomes east-south-easterly.

Coromandel.—On the coast of Coromandel a northerly set prevails within 30 miles of the shore as far north as the parallel of 15° : outside these limits it turns to the north-eastward. North of the parallel of 15° it takes the direction of the land as far as Gordeware Point, and thence trends in an easterly and afterwards a north-easterly direction across the bay. From False Point nearly to Vizagapatam we have a strong south-easterly current of $\frac{3}{4}$ to $1\frac{1}{2}$ mile per hour within 30 miles of the coast; but farther to the eastward it gradually succumbs to the influence of the wind, and joins the general set, first in a north-easterly and then in an easterly direction across the bay.

Arakan.—On approaching the coast of Arakan, the last-

mentioned current becomes more northerly, and finally is governed by the form of that land, and runs strongly to the north-north-westward. It thus becomes a very dangerous current for vessels making Akyab during the south-west monsoon. In such cases it is frequently necessary to heave-to off the port during the night; and if the existence of this current be not known, and proper precaution be not taken to keep to the southward, the vessel may be drifted into dangerous proximity to the reefs to the eastward of the harbour. In some of the works on this subject, all mention of this current is omitted; in others it is represented as running in a contrary direction: it is therefore the more necessary to call attention to it, as either the want of information on the one hand, or the existence of erroneous information on the other, may lead to injury to the greatly increasing trade of Akyab.

Circulation of Currents and Tidal Waves.—This northerly current along the coast of Arakan may probably have a very intimate connection with the southerly current on the coast of Ganjam. They may both belong to the same system of circulation, the Arakan current finding its way to the westward along the sea face of the Sunderbunds and becoming the southerly current at False Point, and being again thrown on the coast of Arakan as before described. But if this be the case, any positive trace of the westerly movement is not to be discerned, or at least is most difficult to recognize in the peculiar rotatory tides which are found to seaward of the Sunderbunds. These tides set, at different periods of each tide, towards every point of the compass. The flood begins at west, at the first quarter it flows west-north-west, at half flood it is about north, the last quarter being to east-north-east. The ebb begins at east, half ebb runs about south, and the last quarter ebb west-south-west, thus forming a complete rotation. But although these rotatory tides go far to hide the current itself, its effects while working its way to the westward are observable in the configuration of the sand-banks off the mouths of the Ganges. The current would here exert its greatest force, and these sands are curved to the westward in a remarkable manner—their very form proving that they are under an influence stronger than that which bends the banks off the mouth of the Hooghly into their south-south-easterly position; the latter being due to the south-west monsoon itself, while the former is the effect of the current of the same monsoon concentrated as it were in a funnel by the shores of Arakan. That the position of the banks off the mouth of the Ganges is *not* caused by the north-east monsoon admits of but little doubt; for this portion of the sea is peculiarly sheltered from the north-east winds, and they cannot be supposed to exert a force sufficient to affect the position of these sand-banks: were it so, the effects of this same force would be apparent in a much

greater degree to the westward; and the sands at the entrance to the Hooghly would lie in a south-westerly direction instead of their present south-easterly one.

South-easterly Current.—A strong current to the south-eastward at the rate of $\frac{3}{4}$ to $1\frac{3}{4}$ mile per hour begins about lat. 18° and long. 90° , flows down towards Preparis Island, and then turns more easterly into the Gulf of Martaban. There is, no doubt, an accumulation of waters in the north-east portion of the bay, caused by the steady blowing of the south-west monsoon across the whole breadth of the sea; and this current seems to be the result of these waters attempting to find an exit. It may be of important advantage to ships from Calcutta bound to ports to the eastward, for it will materially help them in getting to the southward against the wind. From its eastern edge the currents turn off to the north-eastward until, near the coast of Pegu, they become governed by the form of the land, and take a course to the north-north-westward, joining those on the coast of Arakan already described.

Andaman Islands.—The Andaman Islands, which have lately formed the subject of an interesting paper read before this Society, play an important part in the system of currents of the south-west monsoon. They present an obstruction to the general set of the waters in the middle of the sea, and the same phenomena are observable in their vicinity as are to be seen wherever fluids in motion meet with an impediment under similar conditions. The currents rushing to the eastward round the north and south extremes of the islands meet at a short distance beyond them, become confused and irregular, and throw up high ripplings, while immediately under the shelter of the islands an eddy is found running to the northward from $\frac{1}{2}$ to 1 mile per hour. That portion of the sea to the westward of the Andaman Islands is wisely avoided during the south-west monsoon, the reefs lying to windward of the islands presenting dangers to which every prudent mariner would gladly give a wide berth; and I have therefore been unable to find examples of actual experience of the currents to the west of the Andamans; but it is more than probable that the north-easterly set extends close up to the islands, the waters becoming, in a certain measure, heaped up on their west side, and making their way through them and round them wherever they find an opening. Evidence of this action is particularly observable at the eastern mouth of the narrow strait which separates the south and middle Andaman. This strait was closely examined on the occasion of the expedition of which Dr. Mouat was the head, appointed, towards the close of the Indian mutinies, to select a site for a penal settlement in these islands. I may remark, *en passant*, that the manuscript of the original survey of the Great

Andaman by St. Blair, executed at different periods between 1788 and 1796, and drawn on a large scale, was in the hands of the expedition, and was found to be beautifully accurate in all its details. It was our sure guide in the intricacies of channels, of which no other knowledge but that afforded by this chart was to be obtained; and in those few places where it is deficient in the representation of details, we found that they had not been passed over until it had been ascertained that they could be of no practical utility. The geographical position of these islands has also been determined so far satisfactorily, that though it may not be incapable of a still nearer approach to exact truth, yet it has, I believe, attained already to a higher degree of accuracy than can be claimed for the positions at present assigned to many places of far higher commercial importance.

Middle Strait, Great Andaman.—The Strait between the Middle and South Andaman is one of peculiar formation; it is for the most part a narrow, deep crevice between the mountains by which it is bounded on both sides, and which are in no part distant from it much more than 300 yards, while at places the rocks completely overhang it. The channel is thus narrowed at one or two points to about 80 yards, its general breadth being from 400 to 500 yards. Its depth varies, but it is mostly deepest where it is narrowest, 25 fathoms being found where the rocks abut immediately upon the channel, and 6 fathoms where they are more distant; a depth of from 12 to 14 fathoms is, however, very generally found throughout the narrow part of the strait, its western portion, where it runs north and south, being both broader and shallower. Its western entrance from the sea has now a depth of from 4 to 6 fathoms, it having been filled up to some extent during the last seventy years, while the interior of the strait has suffered scarcely any perceptible change. We found no variation in the depth, nor in the contour of the shore; even small islets of less than 50 yards in length appearing in precisely the same state, as to size, elevation, and position, as represented by the first surveyor. But while the depths before mentioned are found in the strait itself, its eastern mouth is almost closed by a bank of sand and mud which has but from 6 to 10 feet water on it; and this I believe may be looked upon as the effect of the current of the south-west monsoon, which being driven, as before described, upon the west coast of the island, finds its way through this narrow strait and deposits at its exit the sediment which it had taken up or set in motion on its passage. The area of drainage of this strait, though small, is sufficient to throw into it a considerable quantity of silt and sand, and the very form of this bank indicates that it has come out *from* the strait, and not that it has been thrown *into* the strait by any effort of the winds and currents of

the north-east monsoon: and moreover were this latter the case some corresponding effects would surely be observable at some of the other openings on the same side of the island, such as Port Cornwallis, the entrances north and south of Sound Island, and Port Blair, at all which places instead of shoals we find deep water. The strait between North and Middle Andaman is completely closed; it is now no longer a strait, if it ever was one: and this is not at all certain; for Blair had not the opportunity of surveying it,—he probably found it impossible to enter even in a boat, as we did.

In the open sea between the Mergui Archipelago and the Andamans, the influence of the prevailing wind again shows itself in a north-easterly set of $\frac{1}{2}$ to $1\frac{1}{2}$ mile per hour.

A south-easterly and south-south-easterly current sets with considerable force down through the Mergui Archipelago and past the Seyer Islands; and from lat. 10° N. and long. 95° E. a strong current in the same direction sets at the rate of $\frac{3}{4}$ to $1\frac{3}{4}$ mile per hour into the entrance of the Malacca Strait. This current may probably be found some degrees farther to the eastward, but I have been unable to gather any facts in support of such a theory, though I know of nothing in opposition to it.

The Ten-Degree Channel, between the Little Andaman and Car-Nicobar Island, is so seldom made use of as a passage for ships during the south-west monsoon, that I have not been able to gather a sufficient number of facts to establish the existing current.

Sumatra.—On the north coast of Sumatra the current of the south-west monsoon follows the form of the land to the westward, but this portion of the sea is sheltered from the influence of the wind. A slight return current to the eastward may be experienced in about lat. $6\frac{1}{2}^{\circ}$ N.

Between Acheen Head and the Great Nicobar an extraordinary current is found running to the south-westward in the teeth of the monsoon at the rate of $\frac{3}{4}$ to $1\frac{1}{2}$ mile per hour; it extends to the parallel of 5° N., and nearly to the 92nd meridian, when it turns to the south and south-east. Where this current meets the ordinary north-easterly set, strong rippings are observed. It may be taken advantage of by ships bound westward from the Straits of Malacca; and though it is at present but little known, its existence is well substantiated by the experiences of the *Herefordshire* in August, 1825, the *Orwell* in July, 1832, the *Marquis Huntley* in August, 1831, H.M.S. *The Royalist* in June, 1845, the *Cambrian* in July and August, 1844, the *Serpent* in 1845 and again 1851, and others.